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MODIFICATIONS TO THE LEBLOND PRECISION LATHE IMPROVES SAFETY IN MACHINING HIGH EXPLOSIVES

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MODIFICATIONS TO THE LEBLOND PRECISION LATHE IMPROVES SAFETY IN MACHINING HIGH EXPLOSIVES

In machining high explosives, three major concerns are safety, reliability, and ease of operation. With these concerns as our main goals, we modified a LeBlond precision lathe for machining high explosives. The result is a unique remote-controlled lathe that shortens downtime, improves accuracy, and reduces interferences from other operations. Since April 1978, the lathe has been operating successfully and safely at LLL's high explosive test facility at Site 300.

The machining of high explosives (HE) is an important part of our nuclear explosive design effort. To properly support the Laboratory's critical hydrodiagnostics testing, we maintain the HE facility at Site 300. At this facility, there are stringent safety requirements that we must follow when handling and machining HE. Also, we are always seeking ways to increase the safeness of our operations. The safety modifications to the LeBlond lathe is one example.

Because we automated the numerical control system, the operator can now program an entire job using computer-generated tapes. He can store an entire part program in computer memory and read it whenever he needs it. We found that storing a part program in computer memory is more reliable than storing it on paper tape.

Another safety improvement we did was to make the computer, numerically controlled machine independent and self contained. Thus, we were able to separate it physically from the other machines. This almost eliminated completely all interferences with other machining operations, and most important, it provides maximum safety for operating personnel.

Considerations in Making the Retrofit

Three considerations dictated our design and implementation of the lathe's modifications:

- The machine must have the required functional operations.
- The machine must be safe and reliable.
- The operator must be comfortable with the control system.

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Required Modifications

At first we considered having a commercial machine tool modified to satisfy our machining requirements. In turn, these machining requirements partially dictated the extent of the required modifications. However, because time and money did not allow us to buy a modified commercial control system, we bought a standard machine tool control and modified it both electronically and mechanically here at LLL.

"Intrinsically Safe" Mode of Operation

Our procedure for operating the lathe is based on the following line of reasoning, which is accepted and followed by other high-explosives facilities of the Department of Energy. We assume that, based on failure probabilities, two distinct failures will not occur at the same time. That is, if a failure occurred in a particular area of the control system, a failure would *not* occur simultaneously in the corresponding safety logic monitoring that condition. This assumption is defined as an "intrinsically safe" mode of operation.

Consideration of the Operator

Of utmost importance in any machine tool retrofit is the human engineering—how the operator interfaces with the control system. The operator must be very comfortable during the machining process and must be able to take corrective action quickly with a minimum amount of thought.

Overview of the Control System

The LeBlond lathe is interfaced to a General Electric Mark Century model 1050 Computer Numerical Control (CNC) specifically designed for multiaxis machine tool control. The CNC has software flexibility, dedicated microprocessors, modular design, and functional board layout. This particular CNC has one 8-bit microprocessor per each of two axes. These microprocessors interpolate motion data and generate axis command pulses. The CNC also has a 16-bit microprocessor that processes the executive-program software and handles all of the software overhead requirements. It was not necessary to modify the GE executive software package in any way. We implemented most of the LLL electronic modifications with standard small- and medium-scale transistor-transistor-logic (TTL) chips and two Intel MCS-48 microcomputers.

Interface to the GE CNC presented no particular problems. Static control status and dynamic control conditions of the lathe are monitored; positional data are stored and processed; set limits are checked; and appropriate action control commands are generated and processed by the control system.

Additional Modifications to the Control System

We also modified the control system to perform the following functions:

Remote Control Capability

Remote and local control capabilities were necessary for operator safety. We placed the GE CNC in a remote control room about 90 ft from the machining room. A local control pendant was designed and interfaced to the system in the machining room. This arrangement provides the necessary operator control for part setup in the local area, complete machining control in the remote area, and adequate operator safety.

Tool Force Monitor

Tool force is monitored and displayed on a real-time basis in both the lateral and vertical directions during the machining operation. Semiconductor strain gages are arranged in a full bridge network that yields a high level of sensitivity. The rate at which tool force readings are made is a function of spindle rpm. When the spindle is below 60 rpm force readings are made two times per second. If the spindle is above 60 rpm, readings are made at the rate of 2½ times per spindle revolution.

Tool force set limits to suit particular machining conditions are selected by the machine tool operator before the machining operations.

If the first or lower force limit is exceeded, a command (feedhold) is generated that causes the tool force to decrease to a safe value. If the force increases until the second or higher set limit is exceeded, an emergency stop command (E-stop) is generated that initiates a safe shutdown of the system.

Spindle-RPM-Limit Detector

Spindle rpm is continuously monitored and displayed on a digital readout during the machining process. For safe machining practice, it is not desirable for the spindle to rpm to exceed an upper limit of 600.

For this reason, two spindle rpm set limits are designed into the TTL logic. If the spindle speed exceeds 525 rpm, a feedhold command is generated that inhibits further axes motion. A further increase in spindle speed to 600 rpm will cause an emergency stop command (E-stop) to be generated.

Storing a Part Program

Paper-tape-reading errors of a part program are responsible for a high percentage of machine tool mishaps. For this reason, we now read and store the entire part program in memory before the actual machining process. After the part program is stored, the microcomputer reads the real-time machining process commands from memory. To have this function, we purchased, as an option in the GE CNC, an additional 12K words of memory to handle up to 120 ft of part-program tape.

Tool-Set Station

During machine tool setup, it is critical that the tool be properly centered on the pole or axis of the part. We designed and installed an electronic tool-set station on the machine that allows the operator to reference the tool quickly and accurately to both small and large parts.

Safe Distance Limit Switches

We added limit switches to protect the operator from a runaway condition while he is exposed to HE in a "live" machine (one that has power applied to it). During the setup procedure, the operator references the tool to the part at the tool-set station and then backs the machine slides away from the part to capture the tool behind the limit switches. He then mechanically "arms" the switches and loads the HE into the machine. It is now safe to leave the room and go to the remote control station. The system is placed in the remote control mode, and the switches are electronically "disarmed." The operator must follow the reverse procedure after the machine operation is completed, and the HE part is unloaded.

Auxiliary Axes Positional Encoders

Redundant positional encoders are coupled to the leadscrew of each axis and also to the spindle. The axes encoders measure the absolute position of the tool, and the spindle encoder signal is used to calculate spindle rpm. The operator can refer to the encoder-derived display and compare the GE CNC "commanded" position with the displayed "absolute" position. The encoder signals are also used for various safety functions such as chip thickness calculation.

Purge of Electrical Cabinets

High explosive dust and chips inside electrical cabinets could cause an explosion if there is an electrical discharge. To guard against this situation, all electrical cabinets in the machining room are purged with a positive air pressure that prevents HE dust and chips from entering the enclosures.

Vacuum and Coolant Flow Monitors

Vacuum and coolant flow are monitored in an effort to maintain overall safe operating conditions. If an unsafe condition develops in the vacuum or coolant flow, appropriate safety action begins automatically.

Microcomputer-Implemented Modifications to the Control System

Two important modifications that we did were to use the Intel MCS-48 microcomputers and associated TTL to control the chip thickness and the surface feet per minute calculations during machining. All logic is wired on a small universal Augat card interfaced to the GE model 1050 CNC system (Figs. 1 and 2).

We chose the Intel MCS-48 microcomputer for several reasons. Although simple arithmetic calculations must be made that may be considered an overkill for the MCS-48, the MCS-48 instruction set is simple to use and is very powerful. In addition, the input-output (I/O) ports are convenient for interfacing to the CNC system logic. The cost in dollars and time looked very attractive, especially since many similar modifications on this CNC as well as other machine tool control systems could be easily implemented with the same MCS-48 family.

Chip Thickness Calculator

The chip thickness calculator (CTC) continuously calculates the real-time value of chip thickness during the actual machining cycle. Chip thickness is the thickness per spindle revolution of the material that is being removed from the part. That is, it is the distance (D_c) that the tool travels tangential to the part in one spindle revolution (Fig. 1).

The CTC microcomputer is programmed to do the following: determine system status; make the actual calculations; compare the results of all these calculations to preset limits; and process an action command if the calculations exceed the preset limits. We wrote the program software in assembly language, and it consists of about 300 instructions.

The process of calculating the actual chip thickness is made five times per spindle revolution. Even at the highest spindle speed of 525 rpm there is plenty of time for the microcomputer to rest between actual process cycle times.

Process Cycle of the Chip Thickness Calculator

Each chip-thickness-calculator process cycle takes one-fifth of a spindle revolution to complete. There are three phases to this machining process cycle: status, calculation, and action.

The status phase begins after the GE CNC system is turned on and the CTC microcomputer is reset and initialized. The microprocessor loops until all system status conditions are met. Before the calculation phase can begin, a chip thickness value of 0.015, 0.035, or 0.86 in. per revolution must be stored in random access memory (RAM) and all other conditions are met (AUTO ON, SPINDLE ON, and NORMAL MODE).

In the calculation phase, the actual value of chip thickness is calculated. Delta x and delta z represent the actual distance the tool travels in one calculation phase (one-fifth of a spindle revolution). The square root of the sum of the squares is computed in software and represents the tangential distance along the normal programmed path that the tool travels in one process cycle.

In the action phase, the CTC microcomputer compares the calculated value of chip thickness to the programmed limit and then takes appropriate action. If the calculated value is less than the programmed limit, the program begins the next process cycle. If the calculated value is equal to or greater than the programmed limit, the process is stopped, and the control

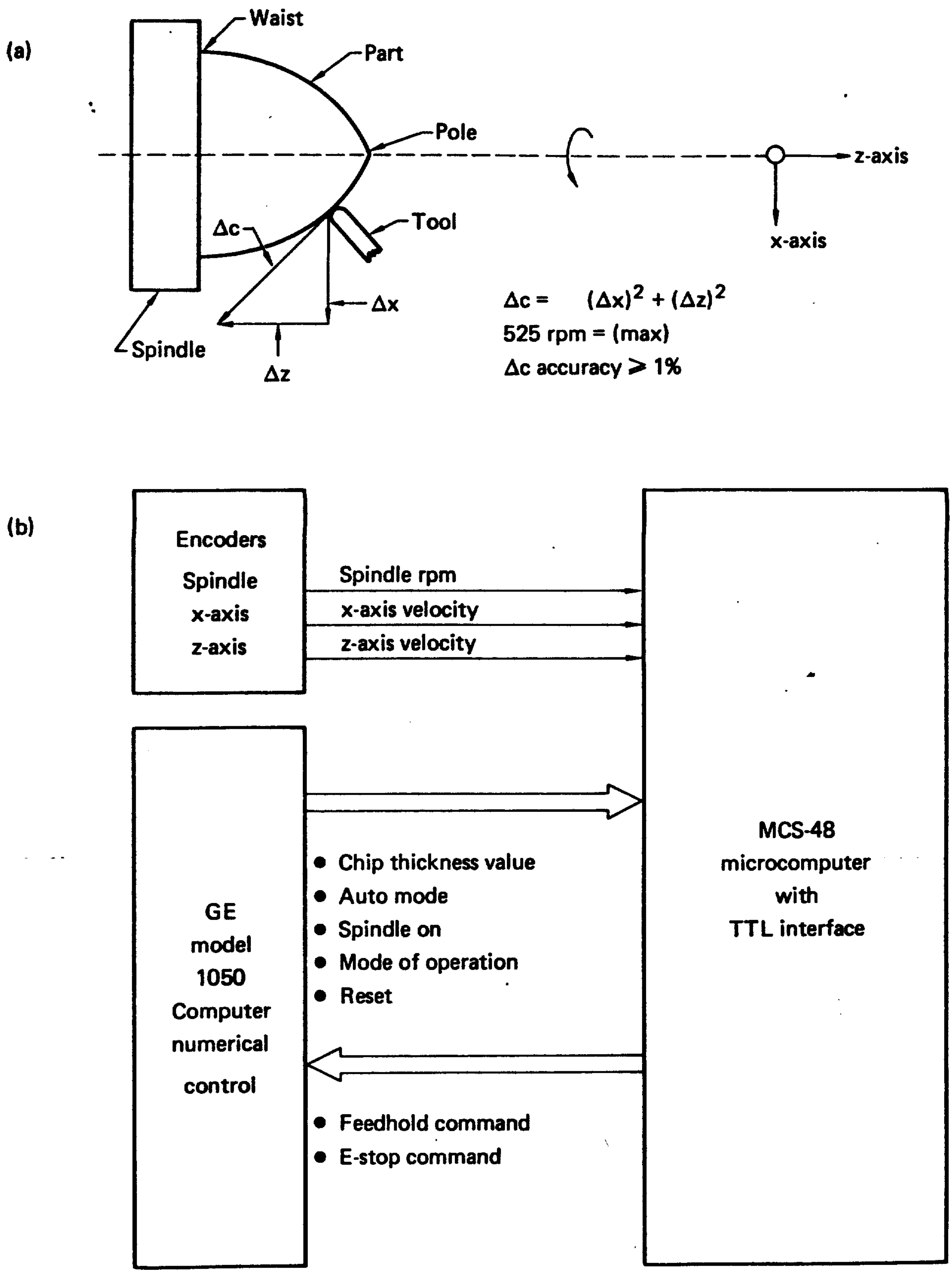

Fig. 1. Chip thickness calculator. (a) Chip thickness equation and top view of lathe. (b) Control system interconnection for chip thickness calculation.

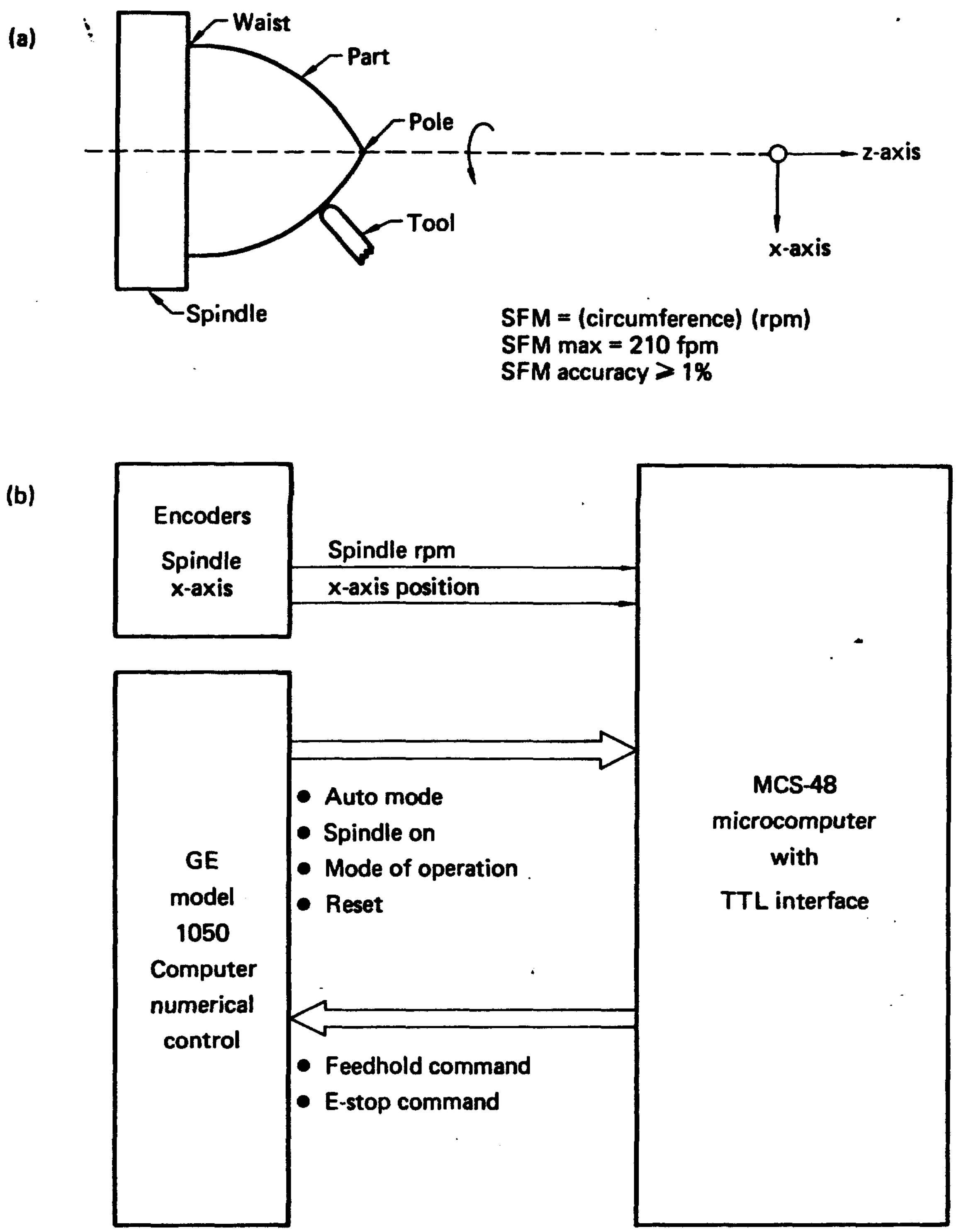

Fig. 2. Surface-feet-per-minute calculator. (a) Surface-feet-per-minute equation and top view of lathe. (b) Control system interconnections for surface-feet-per-minute calculation.

system is given a chance to clear the fault. After five more process cycles, another calculation is made. If the condition still persists, the fault is genuine and could be dangerous. The CTC microcomputer then generates the emergency stop command (E-stop) to the GE CNC that shuts down the system, aborting the machining cycle.

After shutdown, the operator looks at the fault-display panel to determine the problem. The operator then decides on the necessary steps required to correct the problem and restart the machining process.

Surface Feet Per Minute Calculator

The surface feet per minute calculator (SFMC) calculates the real-time value of surface feet per minute (SFM) on a continuous basis during the machining cycle. SFM is the velocity of the tool relative to the part and is a direct function of the tool radius and spindle rpm.

The SFM microcomputer (Fig. 2) is programmed to do the following: determine system status; calculate SFM once per spindle revolution; compare the calculated value of SFM to a preset limit; and process an action command if the calculation exceeds the limit.

Process Cycle of the Surface Feet Per Minute Calculator

The SFMC process cycle takes one spindle revolution to complete. As with the chip thickness calculator, there are three phases to each process cycle: status, calculation, and action.

The status phase begins after the GE CNC system is turned on and the SFM microcomputer is reset and initialized. In this phase, the microcomputer loops until all status conditions are met (AUTO MODE, SPINDLE ON, and NORMAL MODE). Then it goes into the calculation phase.

In the calculation phase, data to compute the spindle rpm are input into the microcomputer. After the spindle rpm is calculated, it is multiplied by the tool radius. This result represents the real-time calculated value of surface feet per minute.

In the action phase, the SFM microcomputer compares the real-time calculated value of surface feet per minute to a set limit of 210 fpm and takes appropriate action in the following circumstances.

If the calculated value is less than the set limit, the processor begins the next process cycle. If the calculated value is equal to or greater than the set limit, the CNC stops generating command pulses to the x and z axes. The SFM microcomputer then checks a timer flip-flop. If the timer is not set, the SFM microcomputer sets it and waits for 1.2 s. If the timer is set, two surface-feet-per-minute calculations in a row have violated the set limit, and the microcomputer will then generate an emergency stop command (E-stop), which causes an orderly shutdown.

As with any condition that causes the system to be turned off, the operator must now look at the fault display panel to determine the problem and to decide what corrective steps must be taken to restart the machining process.

Conclusions

The machining of high explosives will always have its inherent dangers. At LLL, we minimize these dangers by making this process as safe and reliable as possible. This purpose is reflected in the LeBlond lathe retrofit. The modifications to the control system of the lathe were based on modern principles of safe HE machining, including the protection of personnel in adjacent work areas.

The lathe control system became operational at the Site 300 HE test facility in April 1978. At that time, we started an operational "shake down" phase to familiarize the operators with the overall control system. HE parts were machined on a two-shift basis for several weeks. This reduced the backlog of parts considerably. The facility has since returned to one-shift operation, and the control system is performing as expected. The operators feel very comfortable with our modifications and with the overall control system.

Because of the success of this retrofit, we similarly modified a Bostomatic milling machine (converted into a mill/lathe). The LeBlond lathe and the Bostomatic mill/lathe are the first in a series of eight machine tools that are to be modified for machining high explosives. All will meet LLL's requirements of machine safety and reliability.

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